Polyacrylamide Molecular Weight and Phosphogypsum Effects on Infiltration and Erosion in Semi-Arid Soils

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1. Abstract

Seal formation at the surface of semi-arid soils during rainstorms reduces soil infiltration rate (IR) and causes runoff and erosion. Surface application of dry anionic polyacrylamide (PAM) with high molecular weight (MW) has been found to be effective in stabilizing soil aggregates, and decreasing seal formation, runoff and erosion. The objective of this study was to investigate the effects of surface application of granular PAM (20 kg ha^{-1}) of two MW (2×10^5 and 1.2×10^7 Dalton) together with phosphogypsum (PG) (4 Mg ha^{-1}) on the IR, runoff and erosion from semi-arid soils ranging in clay content between 80 and 650 g kg^{-1}, during simulated deionized water rainstorms. Spreading dry PAM (both MWs) mixed with PG was effective in increasing soil IR (3 to 5 times) and reducing erosion (2 to 4 times) relative to the control. The impact of polymer MW on IR and runoff was small, inconsistent and soil type dependent. Conversely, PAM with moderate MW was more effective in reducing soil loss than PAM with high MW. For instance, in the sandy clay, application of amendments resulted in comparable final IR values (15.2 and 15.9 mm h^{-1}), while soil loss decreased from 840 g m^{-2} (in the control) to 370 and 570 g m^{-2} for the PAM with moderate and high MW, respectively. Our results were not consistent with former studies with respect to the effects of PAM MW, probably due to differences in the method of PAM application and soil type.

2. Introduction

Amendments such as gypsum (or phosphogypsum, PG) and anionic polyacrylamide (PAM) have been used to prevent seal formation, runoff and erosion from a wide range of soils (e.g., Levy and Sumner, 1998; Sojka et al., 2006). Use of PG is effective because upon dissolution PG releases electrolytes into the soil solution thereby preventing clay dispersion and aggregate disintegration (Keren and Shainberg, 1981). Water soluble linear PAMs are effective because they stabilize soil aggregaes, prevent clay dispersion and improve clay flocculation (Sojka et al., 2006).

PAM molecular properties (molecular weight and molecular charge density) may interact in affecting PAM's efficacy in flocculating soil clay, stabilizing soil aggregates, diminishing seal formation and resisting erosion (Green et al, 2000). Increasing linear PAM molecular weight (MW) increases the length of the polymer chain; thus, it could be expected that PAM with high MW will be more effective in stabilizing the soil surface and preventing seal formation, runoff and erosion. Conversely, the viscosity of a PAM solution increases substantially with the increase in PAM MW (Volk and Friedrich, 1980) which could impede the flow rate of the solution into and within the soil.

Studies in which the application of dry PAM mixed with gypsum was used resulted in significantly higher final IR and lower runoff and erosion compared to no amendments (control) or application of each amendment alone (Peterson et al., 2002; Yu et al., 2003). The effect of PAM MW, applied in the form of dry granules and mixed with gypsum, on IR, runoff and erosion has not been studied. It is hypothesized that the effectiveness of dry PAM application to the soil surface in decreasing runoff and erosion depends on the balance between the positive impact of PAM MW on its efficacy as a flocculent, and the adverse effect on soil IR of the expected increase in the viscosity of the dissolved-PAM containing soil solution with the increase in PAM MW. Understanding the interactions between those effects may enable combating runoff and erosion from steep slopes exposed to high intensity rain more effectively.

Our objective in this study was to determine the effect of PAM MW, when added as dry granules, on IR, runoff and erosion from five smectitic soils varying in texture.

3. Materials and methods

Samples of five Israeli calcareous, smectitic soils were collected from the cultivated layer (0–250 mm). Selected physical and chemical properties of the soils are presented in Table 1.

The experiments were performed with a drip-type rainfall simulator. A drop fall of 2.2 m was used to obtain drops with a kinetic energy of 16 kJ m^{-3}. Rain intensity was maintained at 36 mm h^{-1} using a peristaltic pump.

Air-dried soils, crushed to pass through a 4.0-mm sieve, were packed in trays 200 by 400 mm, 40 mm deep, over a 20-mm thick layer of coarse sand. The trays were saturated from below with tap water (electrical conductivity of 0.9 dS m^{-1}) and were then placed under the rain simulator at a slope of 15% and exposed to 60 mm of deionized water. During each simulated rainfall event, water infiltrating through the soils was collected, in 4-min intervals and water volume was recorded. Runoff water was collected in buckets continuously throughout the event, and its volume and the total amount of soil removed by the runoff during the entire rain event were determined.

Two types of anionic PAMs (A110 and Cyanamer P-26, from Cytec, Inc., North Andover, MA) were used in this study. The A110, designated PAM(H) had a high molecular weight (1.2 x 10^7 Da) and 15% hydrolysis. The Cyanamer P-26 designated PAM(M) had a moderate molecular weight (2 x 10^5 Da) and 10% hydrolysis. Four treatments were studied: (i) control (no addition of PAM and/or PG), (ii) PG (4 Mg ha^{-1}); (iii) dry PAM(H) (20 kg ha^{-1}) + PG (4 Mg ha^{-1}) and (iv) dry PAM(M) (20 kg ha^{-1}) + PG (4 Mg ha^{-1}). Dry PAM granules and PG grains were spread on the surface of the soil packed in the trays, following the saturation procedure.

4. Results

Effects of cumulative rain on the measured infiltration rate (IR) of the loam and clay-Y soil treated with the amendments, are presented in Fig. 1. It is evident that the amendments were effective in maintaining higher IR values compared with the control in all the soils, and that the degree of effectiveness of the amendments depended on soil type (Fig. 1a,b). Similar trends were noted for the other soils.

Spreading PG or PAM mixed with PG on the soil surface increased the final IR 2 to5 times (12.0 to 33.0 mm h^{-1}) and decreased cumulative runoff, generally 1.5 to 3 times (1.0 to 28.0 mm), compared with the untreated samples (Figs. 2 and 3). Spreading the mixtures of dry PAM with PG resulted, generally, in significantly higher final IR values and lower cumulative runoff values compared with those obtained for spreading PG alone (Figs 2 and 3, respectively). Comparison of the effects of the two PAMs (combined with PG) on the final IR and cumulative runoff indicated that in the loamy sand, loam and clay-E, use of PAM(H) led to higher final IR and lower cumulative runoff than application of PAM(M) (Figs 2 and 3). In the sandy clay and clay-Y, comparable final IR values were observed for the two PAMs but cumulative runoff was lower in the PAM(M) compared with PAM(H).

The effects of PAM(H)+PG treatment on reducing soil erosion in all the soils but for the loamy sand, was comparable to that of PG alone; both treatments were effective in significantly reducing soil loss (> 1.4 times) compared with the control (Fig. 4). However, the PAM(M)+PG treatment was significantly more effective than the PAM(H)+PG (1.3 to 1.8 time) in reducing soil loss relative to the control (Fig. 4).

The observed advantage of PAM(M) over PAM(H) in controlling soil erosion was not in full agreement with previously published data where the effect of PAM MW was reported to depend on site specific conditions (e.g., Green et al., 2000). It is postulated that the disagreement may stem from differences in the methods of PAM application (dissolved PAM vs. dry PAM granules), electrolyte source and soil types. Further studies in which PAM is applied in the form of dry granules are needed to validate our findings.

5. Conclusions

The treatments tested (PG and PAM+PG) were effective in maintaining high final IRs and low levels of runoff and soil loss compared with the control. Comparison of the effectiveness of the two PAMs on the final IR and runoff indicated that it was soil type dependent, hence suggesting that there was little and inconsistent impact to PAM MW. Conversely, PAM(M) was more effective than PAM(H) in controlling soil erosion. The apparent discrepancy between the relative impact of the two polymers on the final IR and runoff and that on soil erosion requires further more detailed studies.

Table 1 Selected properties of the soils studied

Soil Type	Site	Particle-size distribution			$CEC^\dagger$	$ESP^\ddagger$	$CaCO_3$	$OM^\S$	$pH^\P$
		sand	silt	clay					
		------ $g\ kg^{-1}$------			$cmol_c\ kg^{-1}$	%	$g\ kg^{-1}$	$g\ kg^{-1}$	
Loamy sand	Basra	870	50	80	8.75	1.1	1.26	0.8	7.11
Loam	Nevatim	413	362	225	17.68	2.10	182.4	12.2	7.82
Sandy clay	Hafetz Haim	465	154	381	34.76	1.63	96.2	11.0	7.46
Clay-Y	Yagur	145	342	513	57.43	1.64	202.0	17.6	7.61
Clay-E	Eilon	137	213	650	64.90	1.12	4.62	18.2	7.33

†CEC = Cation exchange capacity; ‡ESP = Exchangeable sodium percentage; §OM = Organic matter; ¶pH from saturated paste extract.
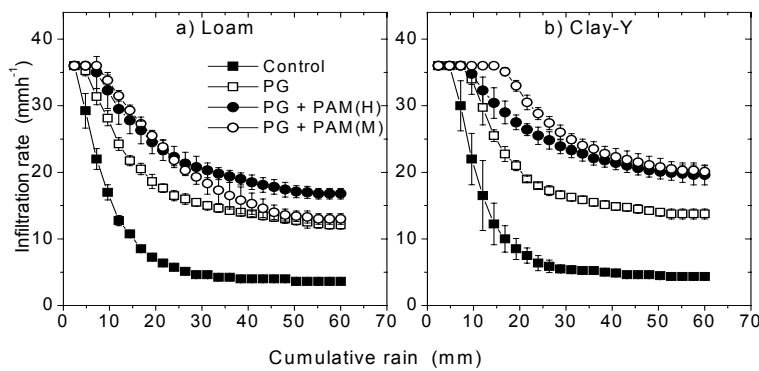

Figure 1 Infiltration rate curves for the loam (a) and clay –Y (b) soils. Bars indicate one standard error. Control (no amendments); PG, phosphogypsum (4 Mg ha⁻¹); PAM(H) & PAM(M), polyacrylamide with high- and low-molecular weight (20 kg ha⁻¹), respectively
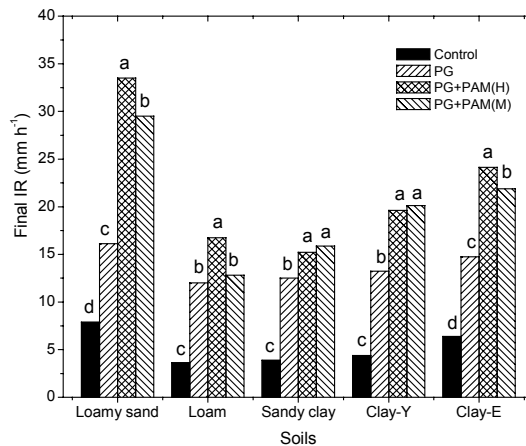

Figure 2 Final infiltration rate (IR) as a function of the treatments for the five soils. Within a soil type, bars labeled with the same letter are not significantly different at *P*<0.05 level. Control (no amendments); PG, phosphogypsum (4 Mg ha⁻¹); PAM(H) & PAM(M), polyacrylamide with high- and low-molecular weight (20 kg ha⁻¹), respectively
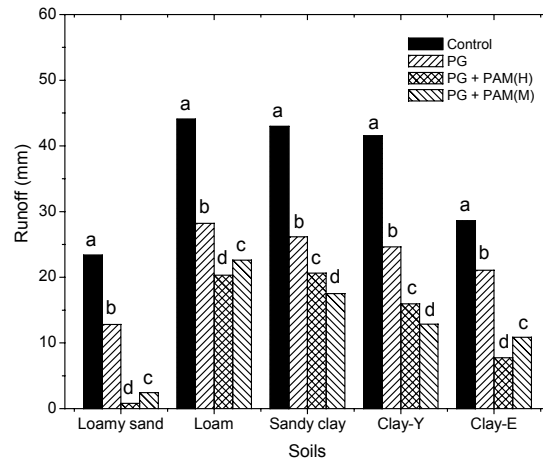
Figure 3 Cumulative runoff as a function of the treatments for the five soils. Within a soil type, bars labeled with the same letter are not significantly different at *P*<0.05 level. Control (no amendments); PG, phosphogypsum (4 Mg ha^{-1}); PAM(H) & PAM(M), polyacrylamide with high- and low-molecular weight (20 kg ha^{-1}), respectively
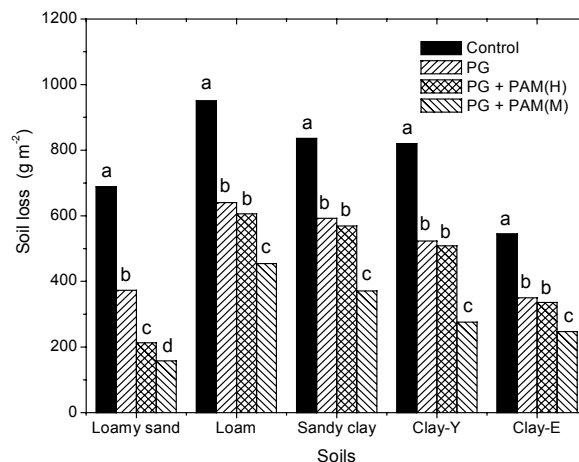
Figure 4 Total Soil loss as a function of the treatments for the five soils. Within a soil type, bars labeled with the same letter are not significantly different at *P*<0.05 level. Control (no amendments); PG, phosphogypsum (4 Mg ha^{-1}); PAM(H) & PAM(M), polyacrylamide with high- and low-molecular weight (20 kg ha^{-1}), respectively

6. References

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